Status of the Pbar Source

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DOE Review

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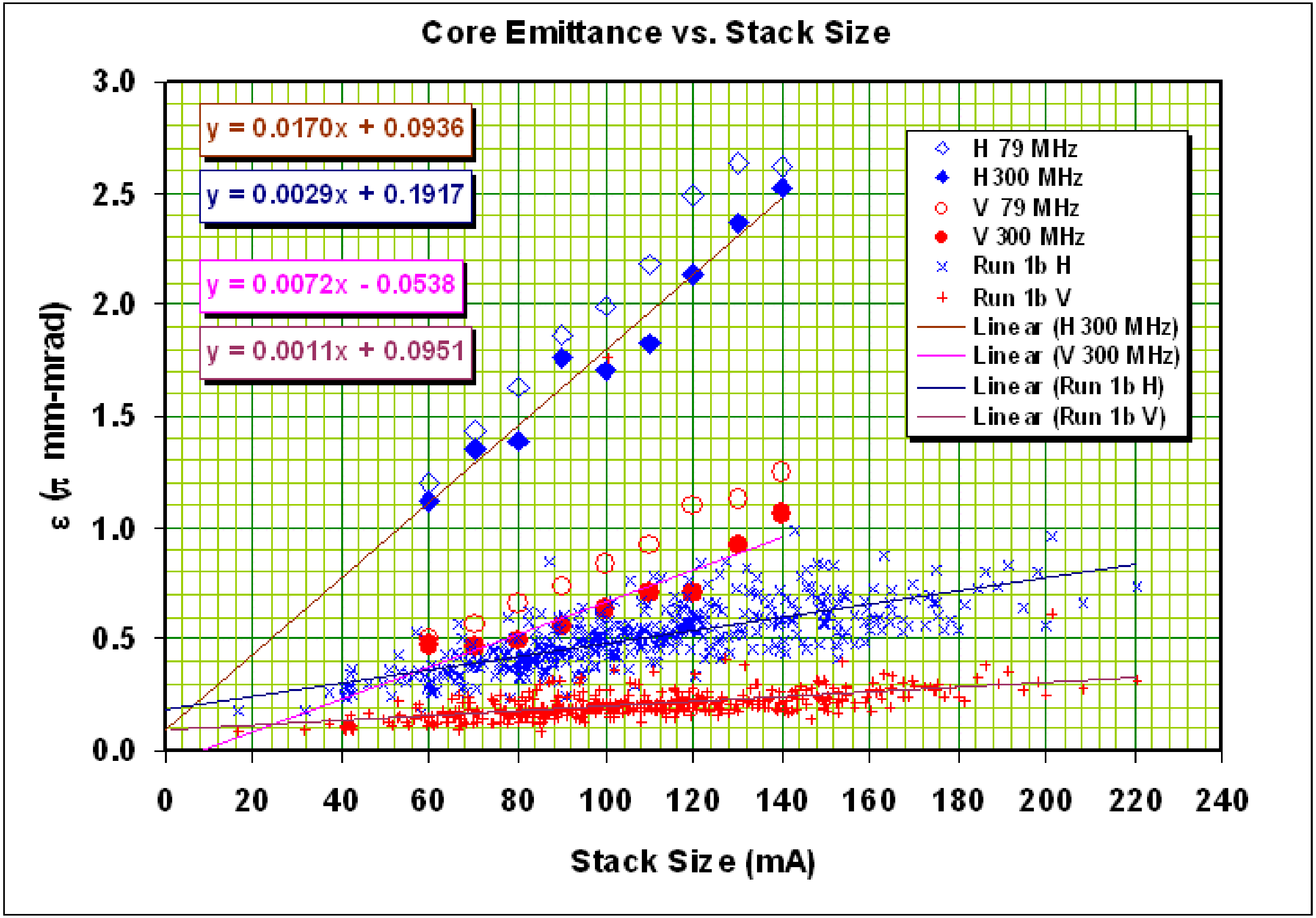
Overview

- The present pbar production rate which is at 66% of the design value is adequate to support present Run II operations.
- Before July of 2002, the horizontal emittance of a typical 100E+10 antiproton stack was about a factor of 2 larger than the Run II handbook design value.
  - At a stack of 100E+10 pbars the normalized horizontal transverse emittance was about 17 π-mm-mrad.
  - The Run II handbook specifies 8 π-mm-mrad at 100E+10 pbars
- During the period of Nov. 2001 through July 2002, almost 100% of the manpower and machine study time of the Pbar Source department was devoted to trying to reduce the horizontal emittance.
- We believe that the horizontal emittance growth was caused by
  - Intra-beam scattering (60%)
  - Trapped ions (40%)
- The intra-beam scattering (IBS) heating of the beam is worse now for Run II than it was in Run I because of the changes in beta functions that were the result of the Accumulator Lattice Upgrade

Transverse Emittance



Accumulator Run II "Upgrades"

(why did we change the Accumulator Lattice)

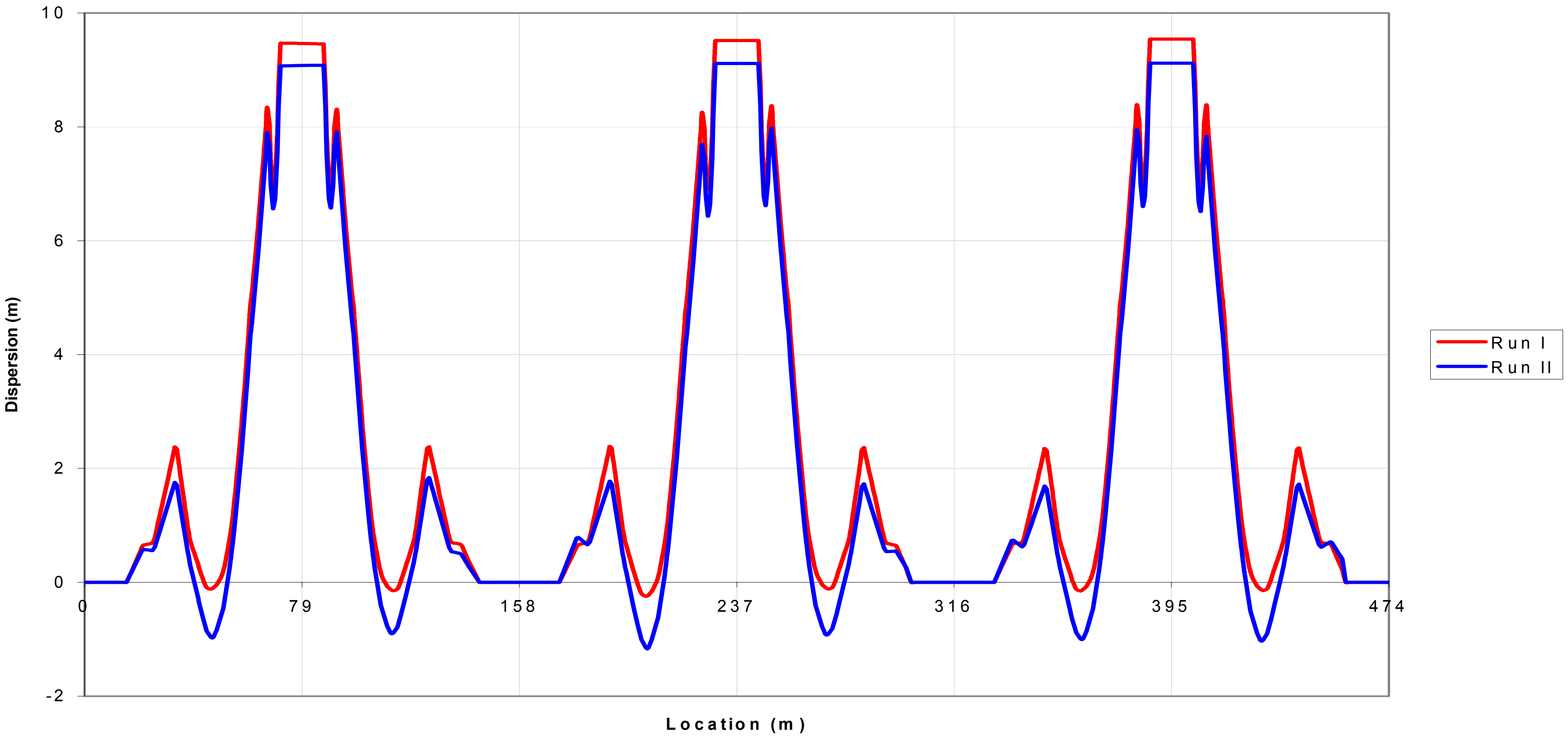
- Main Injector Project was to increase the antiproton flux into the Accumulator by a factor of 2.7
  - A factor of 1.7 increase in the number of protons on target
  - A factor of 1.6 increase in 120 GeV proton production rate

$$\Phi = \frac{W^2 \eta E_d}{f_0 p \ln\left({F_{\min}} \big/ {F_{\max}} \right)}$$

Antiproton flux though the Accumulator Stacktail Momentum Stochastic Cooling system

- Bandwidth W to increase from 1-2 GHz to 2-4 GHz
  - 15 meters of new Stacktail Pickup Arrays in A60
  - 15 meters of new Stacktail Kicker Arrays in A30
- Changed Accumulator lattice to keep Stacktail system stable
  - Schottky bands must not overlap in the Stacktail frequency range
    - Maximum frequency of the Stacktail system increased from 2 GHz to 4 GHz
    - η must decrease from the Run I value of 0.022 to 0.012 in Run II
    - γ_t must increase from the Run I value of 5.5 to 6.55 in Run II

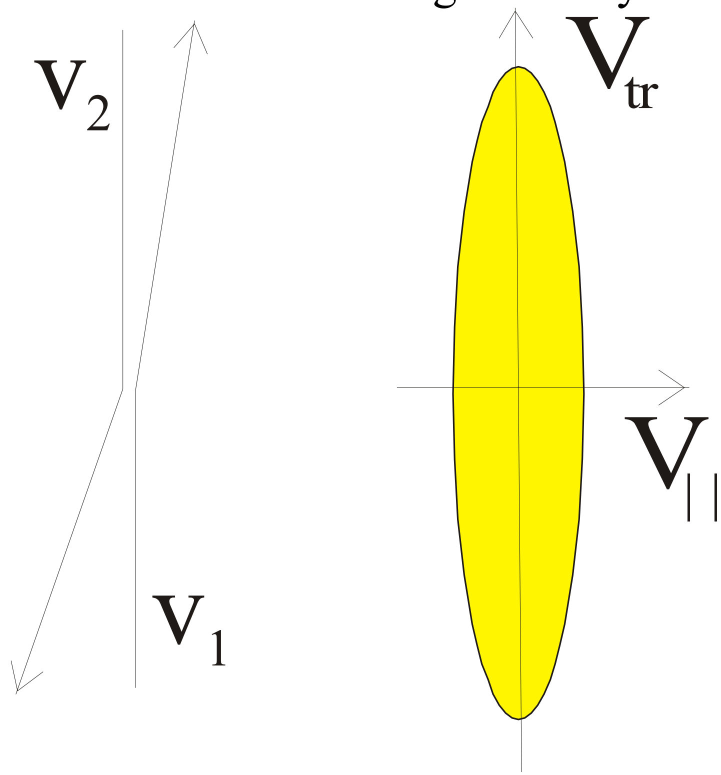
Accumulator Lattice Upgrade



- γ_t increase was obtained by adding negative dispersion at the “B7” bends
- Shunts were added to 6 of the 14 quads in each of six sectors
- The quads on either side of each of the high dispersion straight sections were increased in strength

Intra-beam Scattering

- In the beam frame, if the longitudinal momentum spread is much less than the transverse momentum spread, the IBS formulas can be significantly simplified



Transverse IBS Growth Rate

- The heating of the longitudinal degree of freedom causes cooling for both transverse degrees of freedom.
- Additional mechanism heats the horizontal degree of freedom
  - At regions with non-zero dispersion, changes in the longitudinal momentum change the particles reference orbits, which additionally excites the horizontal betatron motion

$$\frac{d\varepsilon_x}{dt} = \frac{1}{2}\left\langle A_x \frac{d\theta_{\parallel}^{\ 2}}{dt}\right\rangle_s \qquad \text{where} \qquad A_x = \frac{D^2 + \left(D'\beta_x + \alpha_x D\right)^2}{\beta_x}$$

Coefficient ½ is related to the fact that the beam is unbunched

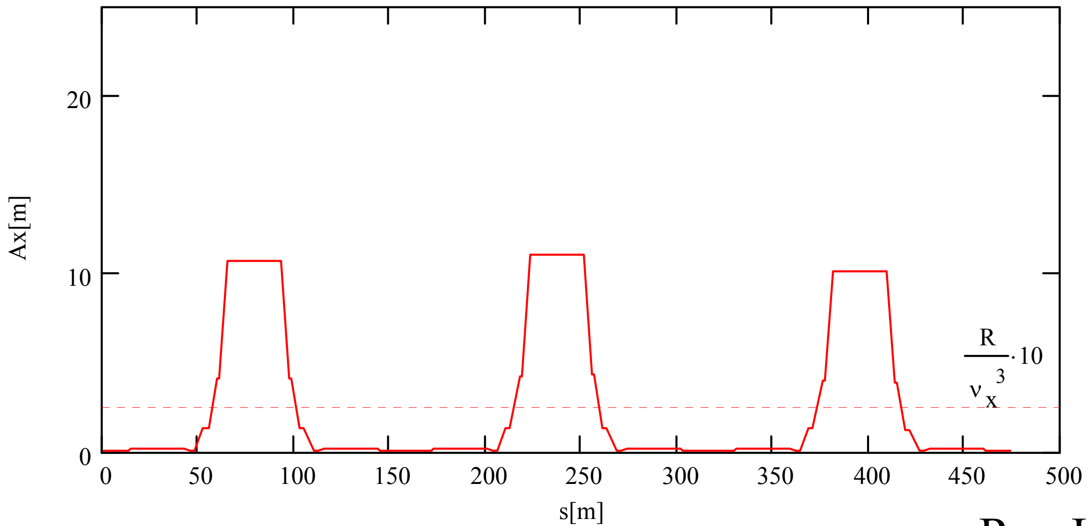
- Finally, one can write for the emittance growth rates

$$\frac{d\varepsilon_{x,y}}{dt} = \frac{\sqrt{2\pi}e^4 N L_C}{8 m_p^{\ 2} c^3 \gamma^3 \beta^3 C}\left\langle \frac{1}{\sigma_x \sigma_y \sqrt{\theta_x^{\ 2} + \theta_y^{\ 2}}}\begin{bmatrix} 2A_x \Xi_{\parallel}\left(\theta_x, \theta_y\right) - \dfrac{\beta_x}{\gamma^2}\Xi_{\perp}\left(\theta_x, \theta_y\right) \\ -\dfrac{\beta_y}{\gamma^2}\Xi_{\perp}\left(\theta_y, \theta_x\right)\end{bmatrix}\right\rangle_s .$$

where $$\Xi_{\perp}(x,y) \approx 1 + \frac{2\sqrt{2}}{\pi}\ln\left(\frac{\sqrt{3x^2 + y^2}}{2y^2}x\right) + \frac{0.5429\ln(y/x)}{\sqrt{1+\ln^2(y/x)}}$$

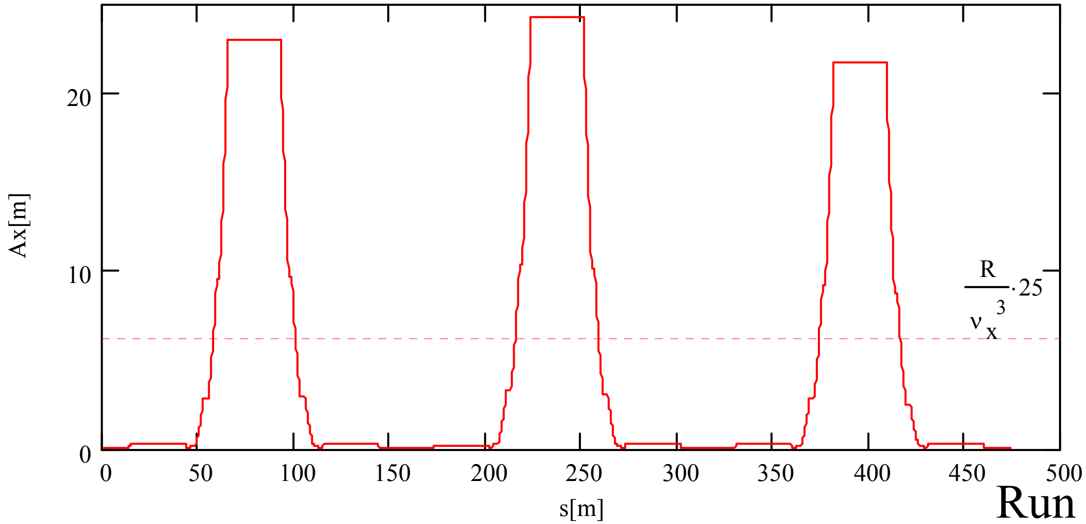
V. Lebedev

Run I and Run II Accumulator Lattices



Run I Lattice

- Both lattices are not designed to have small IBS
- Run II lattice amplifies IBS by more than factor of two in comparison with the Run I lattice.



Run II Lattice

Plan for Emittance Control

- We developed a two-fold plan to reduce the transverse emittance:
  - Better transverse stochastic cooling of the Accumulator core.
    - The bandwidth was increased by a factor of 2
    - The center frequency of the band was increased by a factor of 1.5
  - Dual lattice operation mode of the Accumulator
    - Keep the "fast stacking" lattice (η=0.012) for pbar production
    - During shot setup, ramp the lattice with the beam at the core orbit to the "IBS" lattice (η=0.022)
      - The "shot" lattice will reduce the intra-beam scattering heating by a factor of 2.5
      - The "shot" lattice will increase the cooling rate by a factor of two increase in mixing due to the change in η

$$\frac{d\varepsilon}{dt} \approx -\frac{\varepsilon}{\tau_{cool}} + \frac{Heat}{\varepsilon^{3/2}}$$

Center freq.

Ions

IBS

$$\frac{\varepsilon_{old}}{\varepsilon_{new}} = \left(\frac{\tau_{cool_{old}}}{\tau_{cool_{new}}}\frac{Heat_{old}}{Heat_{new}}\right)^{2/5} = \left(2 \times 1.5 \times 2\right)^{2/5} \times \left(\frac{0.4 + 0.6}{0.4 + \frac{0.6}{2.5}}\right)^{2/5} = 2.4$$

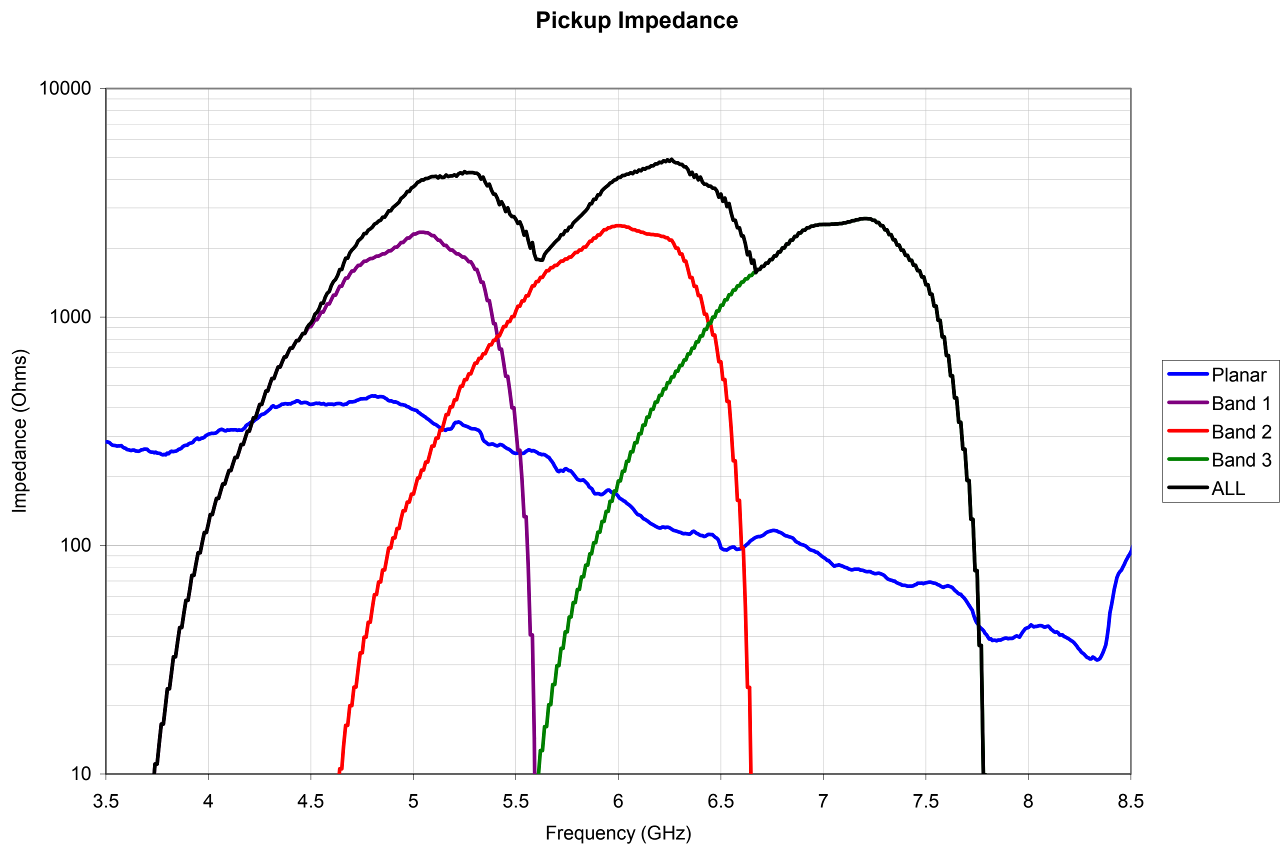
Bandwidth

Better Mixing

Reduced IBS

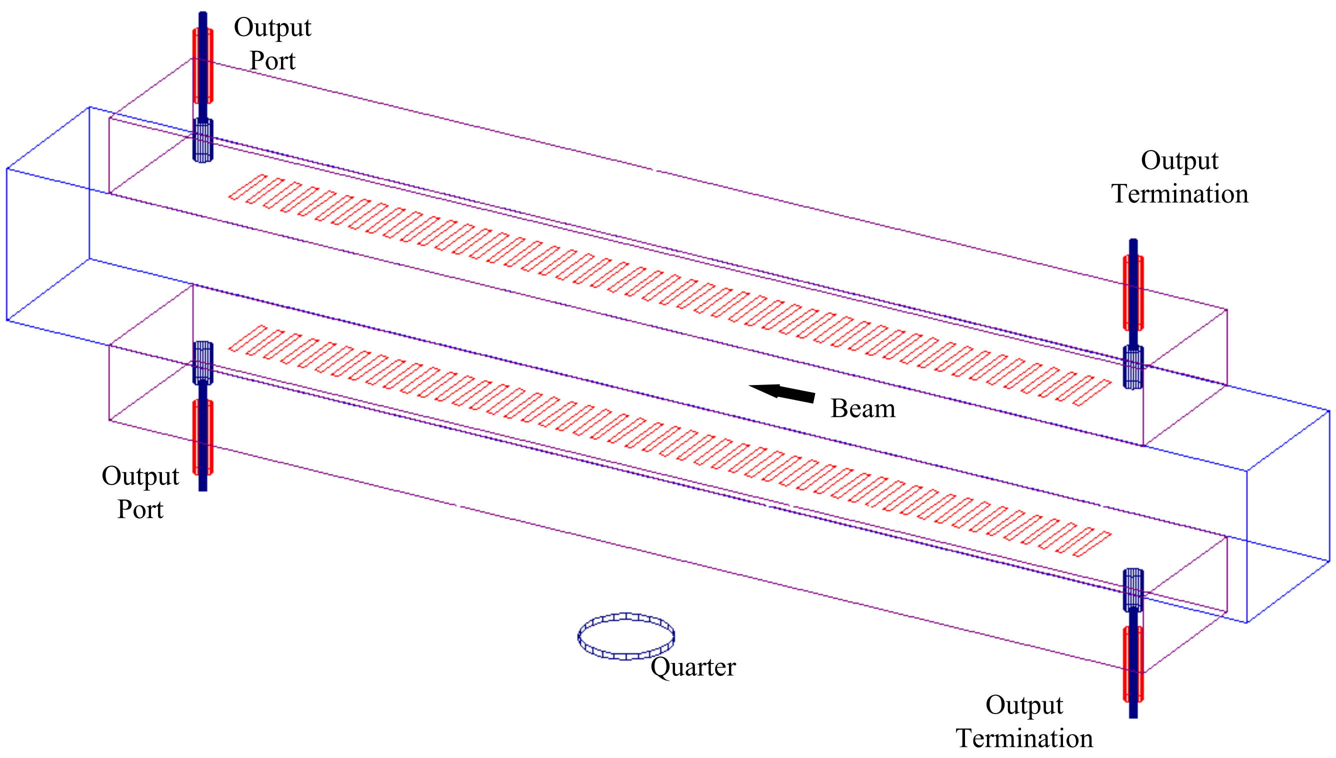
Accumulator Core Cooling Upgrade

- Initial Run II system consisted of a 2-4 GHz band and a 4-6 GHz band
  - The 2-4 GHz band is ineffective because of the small value of η
  - The 4-6 GHz band suffers from poor signal to noise.
- Replaced both core bands with a 3 band Debuncher style system
  - Better sensitivity
  - More bandwidth (2x)
  - Better mixing factor (1.5x)



Slow Wave Structures

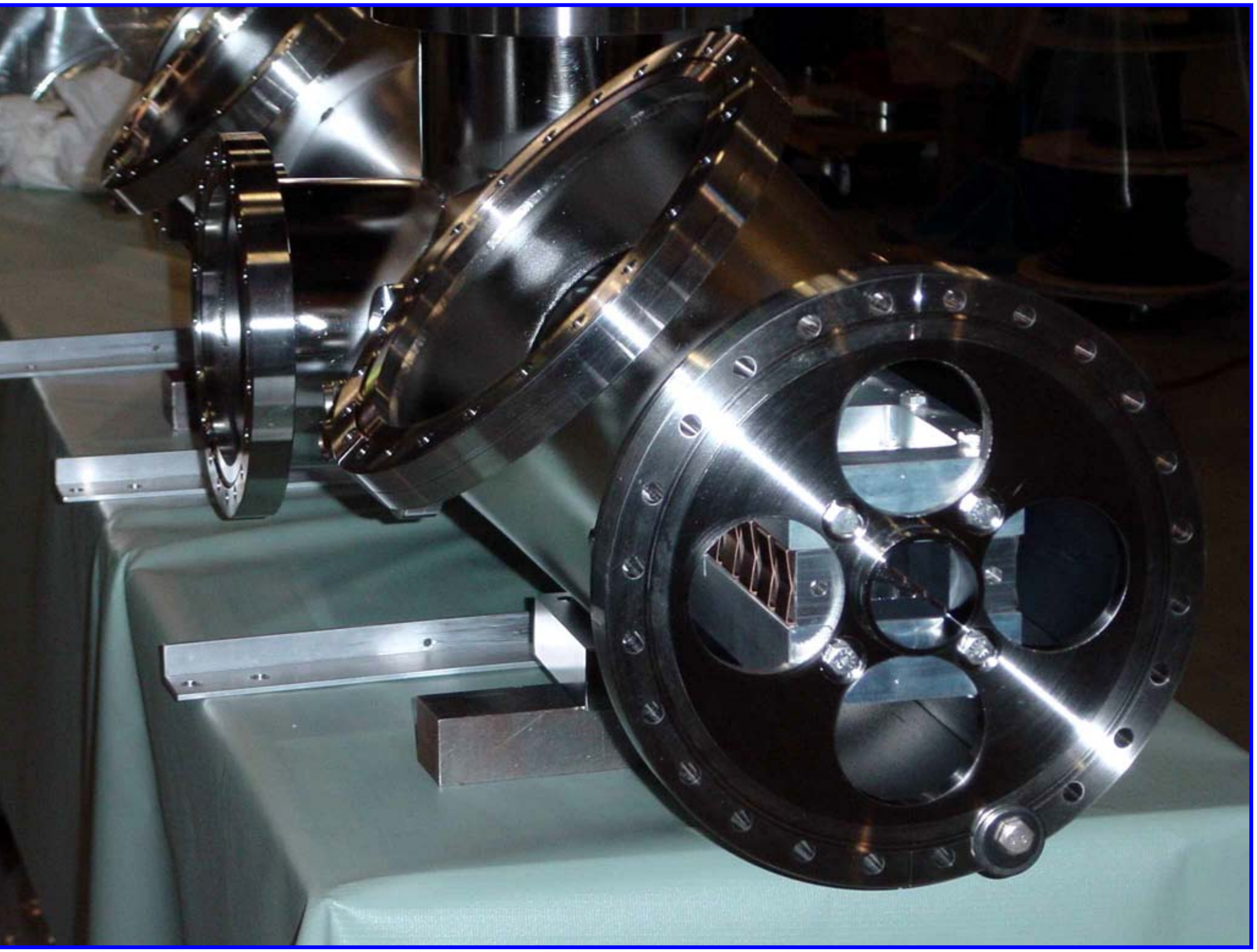
- The core cooling upgrade consists of slow-wave structures
- When the beam pipe can support a microwave mode (> 5 GHz in the Accumulator), binary combiner boards become ineffective
- The beam pipe of a slow-wave structure is designed to be above cutoff
- The slots of a slow-wave structure slow the phase velocity of the waveguide to match the beam velocity



Core Cooling Arrays

- Project was started 10/30/01 and completed 6/15/02 (7.5 months)
  - 6 new cooling systems
  - 4 new ultra-high vacuum tanks
- The effective cooling rate of the new system is 1.4x faster than the combined rate of the old systems

Core Cooling Tank

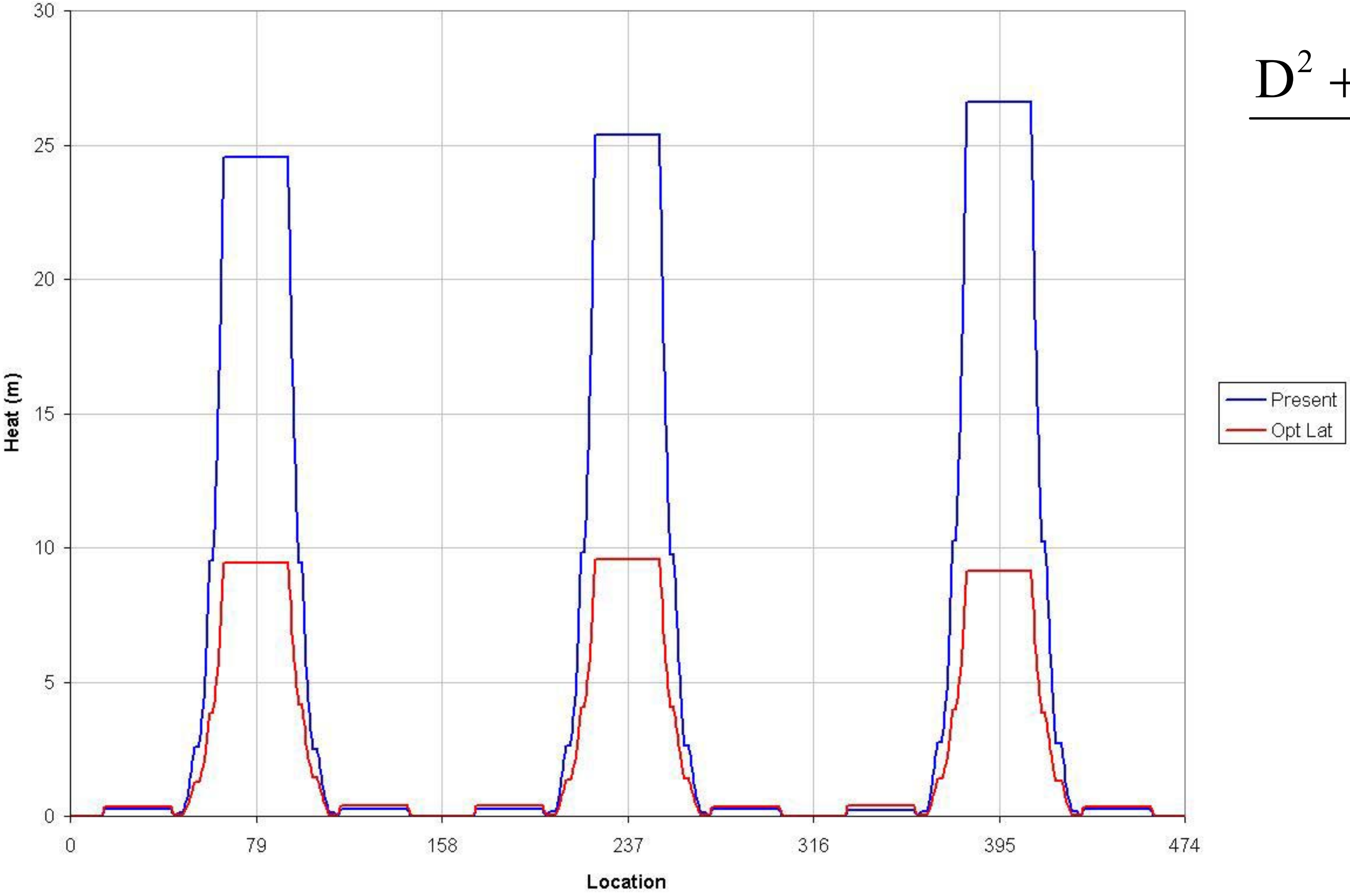


- With full system equalizers the new system will be 2.5x faster than the combined rate of the old systems
- With an 82 mA stack, we have a peak signal to noise ratio of 8 dB at 7.5 GHz for a 7 pi normalized emittance

Accumulator "Shot" Lattice

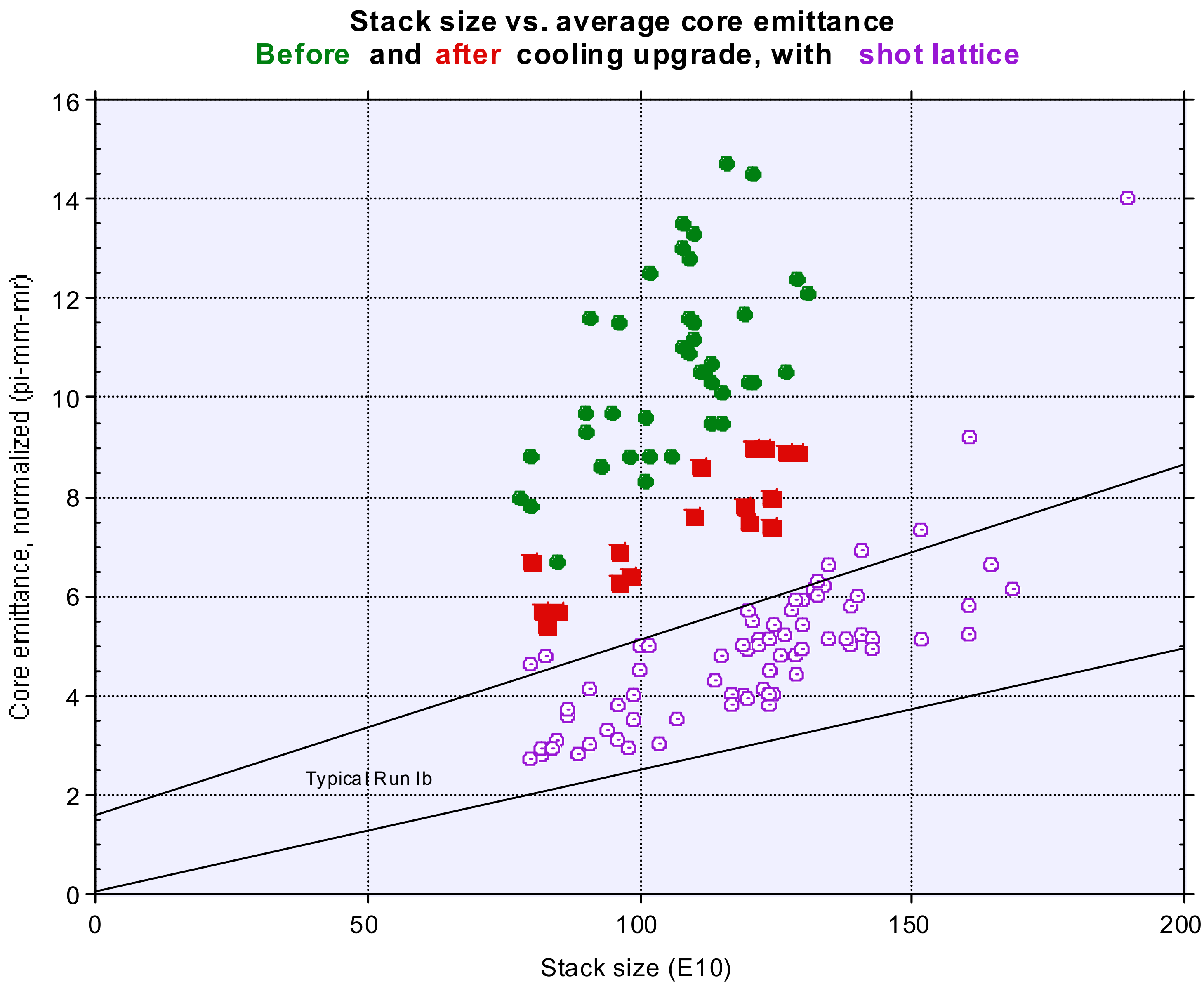
- An Accumulator lattice with a much smaller IBS heating term was designed.
- The lattice was designed with the following constraints
  - No hardware changes to the present quadrupole configuration.
  - Same betatron tunes as the present Run II lattice
  - Zero dispersion in the odd straight sectors
  - High dispersion in the even straight sectors
  - Correct betatron cooling phase advances
  - Correct kicker phase advances
  - $\gamma_t < 5.5$ ($\eta < 0.022$)
- Ramp Development began 4/9/02 and dual lattice mode became operational 7/17/02
  - Ramps are 100% efficient
  - Tunes are controlled to within 0.0005
  - Orbits are controlled to within +/- 1mm
  - Ramping from the Stacking Lattice to the Shot Lattice adds about 15 minutes to shot setup.

Accumulator Lattice IBS Heating Term



$$\frac{D^2 + \left(\beta D' + \alpha D\right)^2}{\beta}$$

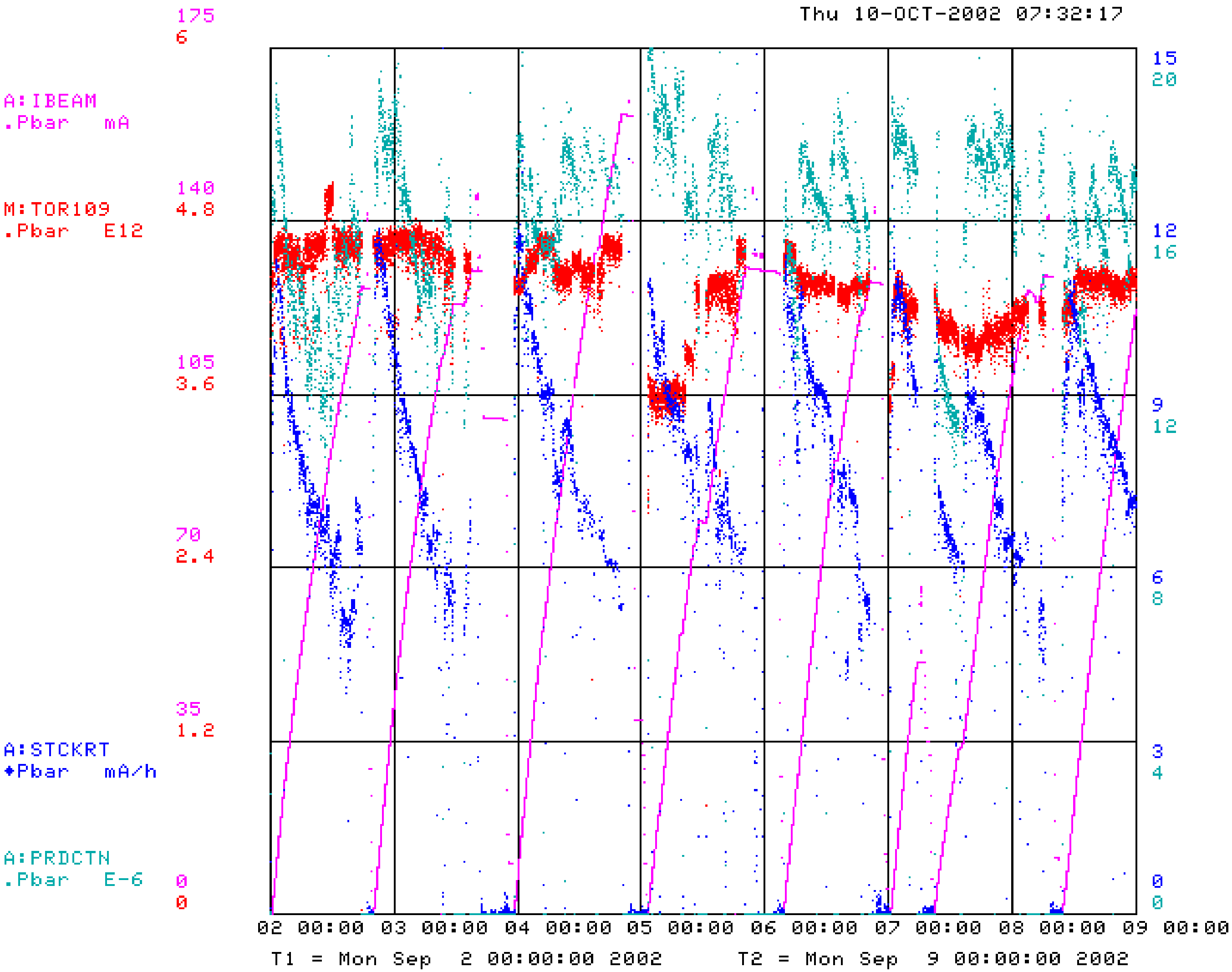
Antiproton Source Emittances



Antiproton Source Short-Term Goals

- With antiproton source emittances under control, the focus of the Antiproton Source Department has shifted to increasing the stacking rate.
- We have achieved
  - an initial stacking rate of 12.4 mA/hr
  - An average a production efficiency greater than 15×10^{-6} pbars/proton
  - An initial production interval of 2.2 seconds
  - A stack of 160 mA in a 20 hr period.
- Our immediate goal is to achieve the initial Run II design goal of 18.5×10^{10} pbars/hour with no stack
  - Production efficiency = 16×10^{-6} pbars/proton on target
  - Initial production interval of 1.5 seconds
  - Be able to stack to a 200 mA stack in a 20 hr period.
    - Stack at 16 mA/hr for a stack size of 50 mA
    - Stack at 13 mA/hr for a stack size of 100 mA
    - Stack at 9 mA/hr for a stack size of 150 mA
  - Be able to shoot from a 200 mA stack with emittances below 10pi (normalized)

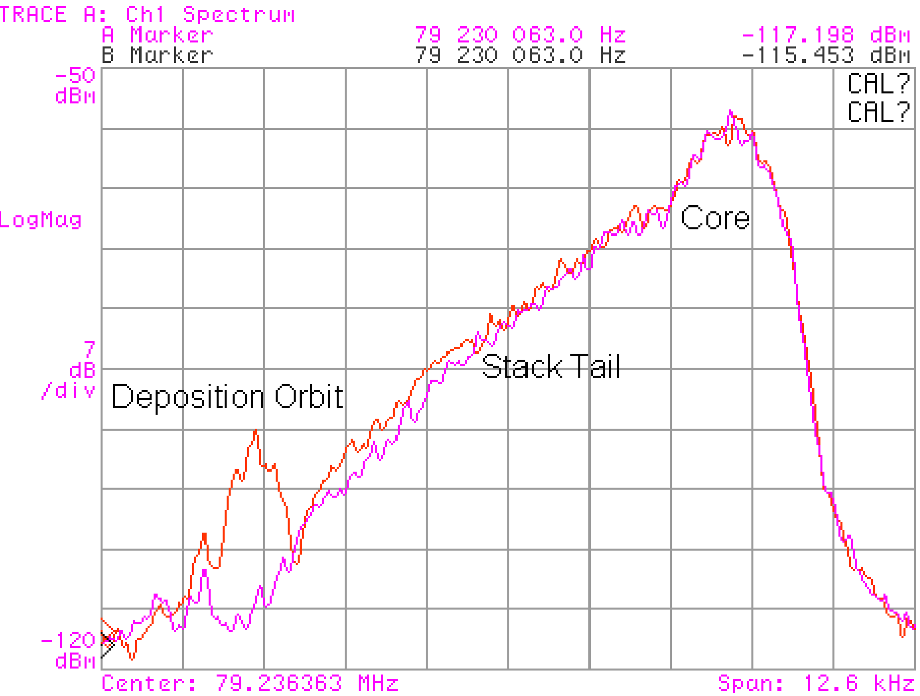
Present Pbar Stacking Performance



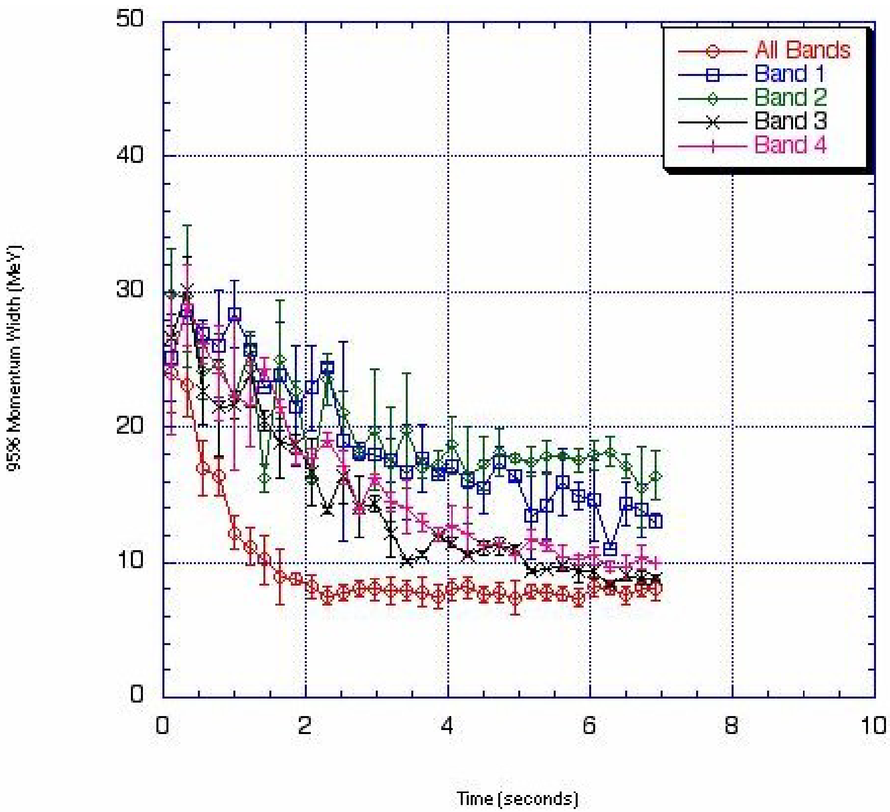
- We can achieve our stacking goals if we can reduce the initial production cycle time from the present 2.2 seconds to the design 1.5 seconds

Why is the Cycle Time so Slow?

Accumulator Longitudinal Spectrum



Debuncher Momentum Spread vs. Cycle Time



- Beam must be cleared off the Stacktail deposition orbit before next beam pulse.
  - The more gain the Stacktail has, the faster the pulse will move.
  - The Stacktail gain is limited by system instabilities between the core beam and the injected beam
- For a given Stacktail gain, the larger the momentum spread of the injected pulse, the longer it takes to clear the pulse from the Stacktail Deposition orbit.
  - The momentum spread coming from the Debuncher is too large.

Stacking Projects

- Debuncher Momentum Cooling Improvements
  - Smaller momentum spread delivered to Accumulator, which would permit faster cycle time. Faster cycle time would increase stacking rate at low and high stacks
- Transverse Debuncher Notch Filters for Bands 1 & 2
  - Removal of longitudinal lines would permit for larger transverse cooling gain which would permit faster stacking cycle times.
- Commission Core Momentum-Stacktail Compensation Legs
  - Keep the stacktail stable at high stacks. Stacktail gain could be increased. Faster stacking at large stacks would result.
- Implement Core Momentum "Spreading" during stacking
  - Keep the stacktail stable at high stacks. Stacktail gain could be increased. Faster stacking at large stacks would result.
- Stacktail Notch Filter Upgrade
  - Increasing bandwidth of the stacktail will permit faster stacking rates
- Develop Improved Transverse Compensation of the Stacktail
  - Reduce heating of the transverse heating of the core via the stacktail which would permit a faster rep rate at large stacks.
- AP1 Bunch by Bunch length monitor
  - Measure effective longitudinal emittance provided by MI so we can identify sources of emittance growth in MI. Reduce bunch length on target will permit for a faster stacking cycle time.

Emittance Control Projects

- Finish the return ramp from the shot lattice to the stacking lattice.
  - Larger stack sizes by about 15%. Faster return to stacking i.e. more stacking time by about ½ hour (3%)
- Bands 2&3 Transverse Core Cooling Equalizers
  - Increase in Cooling bandwidth by about 0.6 GHz (20%) Lower emittances by 7%
- Build 1-Q Transverse Damper for the Accumulator
  - Reduce ion instabilities which would permit for smaller transverse emittances during shots to the TEV
- Make Flying Wires in Accumulator Operational
  - Help monitor Accumulator emittances
- Commission Accumulator Quadrupole Pickup
  - Will be used to determine beamline match. Will help make pbar emittances in the Main Injector smaller

Long Term Projects

- In order to support an ultimate luminosity of 400×10^{30} cm^{-2} sec^{-1}, the pbar production rate must climb to 55×10^{10} pbars/hr
- The Antiproton Source Department has made significant progress in the following projects (progress should be discussed in break-out sessions)
  - New Target Optics
    - 1st pass Lattice Design complete
  - Target Material Study
    - Inconel 600 study complete
    - Inconel 625 study in progress
  - Target Sweeping
    - Rebuild complete
    - Pulse testing in progress
    - Installation during January '03 shutdown
  - Lithium Lens Upgrade
    - Assembly process upgrade
      - Chemical processing
      - Pre-load studies
      - DAQ
    - Diffusion Bonded Lens Prototype
      - Prototype #1 to be filled within next month and tested to failure
      - Prototype #2 fabrication in process.

Long Term Projects (continued)

- New trims in the AP2 line
  - To be installed in January 03 shutdown
- Moveable Debuncher Quad stands
  - 10 of thirty fabricated – to be installed in January '03 shutdown
- Debuncher BPM Upgrade
  - Prototype testing completed.
  - Full system to be installed in Spring of '03.
- AP2 Debuncher Aperture Upgrade
  - Largest single component of future upgrades – possible increase in production efficiency 2.3x
  - Three accelerator physicists are assigned (Gollwitzer, Werkema, Derwent)
  - Three engineering physicists are assigned (Vander Meulen, Sondgeroth, Budlong)
  - Beam Study plan has been developed.
  - Collaboration with Technical Division forming.

Summary

- Pbar Source is presently supplying enough antiprotons with a sufficient phase space density to support a luminosity in excess of 50×10^{30} cm^{-2} sec^{-1}
- Stacking rate is 66% of the Run II Handbook design goal
  - Stacking problems have been clearly identified with large momentum spread coming from Debuncher and Stacktail system instabilities
  - Projects and resources have been identified to increase the stacking rate.
- The groundwork for long-term high luminosity upgrades is proceeding steadily
  - A significant amount of manpower is being re-focused to long-term projects
  - These long-term projects are in the initial planning stage.
- Pbar Source Personnel have clearly shown that they are capable of building complicated hardware projects and solving difficult accelerator physics problems.